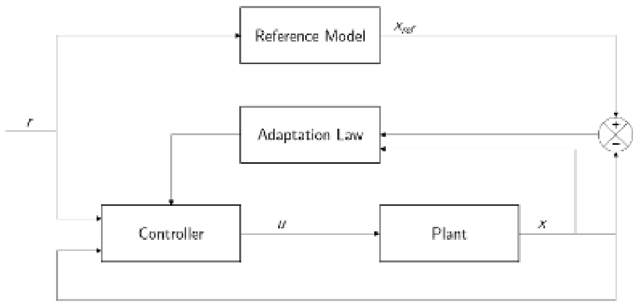
AE 434 – Spacecraft Control

Lecture 1

Introduction

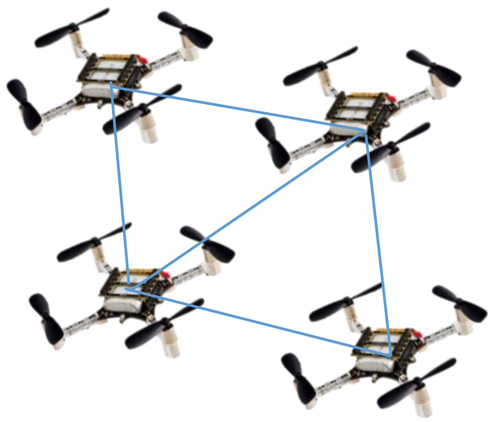
Spring 2023

General Information



Instructor: Dr. Diana F

e-mail: festaodb@erau.edu



Lecture times and room:

MWF 5:00PM – 5:50 PM (LB 369)

Office hours (LB 227):

W 11:00AM – 1:00PM

F 12:00PM – 2:00PM

Coursework

Homework:

- Generally assigned every Monday
- Generally due Friday
- Solutions posted on due date after submission

Quizzes:

- About 3-4 in-class quizzes

Exams:

- 2 exams
- Dates TBA

Grading

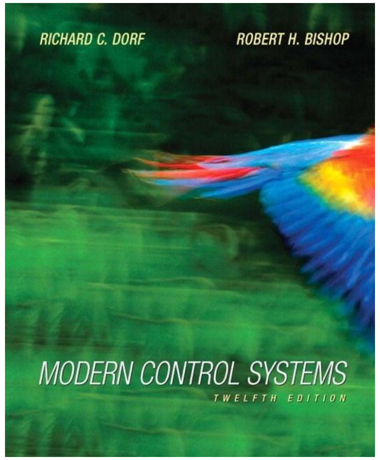
Homework	25%
Quizzes	5%
Exams	30%
Project	40%

Neatness and clarity are a <u>must</u> for all homework/exams

Class Policies

1. Missed HWs cannot be made up.
2. Missed exam cannot be made up.
3. Late submission is not allowed.

Textbook and References



Main Textbook:

Richard C. Dorf, Robert H. Bishop, *Modern Control Systems,* ISBN: 9780131383104. **Any Edition**

Suggested Supplementary Materials:

Nise, Norman S., *Control Systems Engineering*, John Wiley & Sons, 2011. ISBN 978-0470-54756-4, ISBN 978-0470-91769-5. Any Edition

Ogata, Katsuhiko, *Modern Control Engineering*, Prentice Hall, New Jersey, 2002. ISBN 0-13-060907-2. Any Edition

Anton H. de Ruiter, Christopher Damaren, James R. Forbes, *Spacecraft Dynamics and Control*, ISBN: 9781118403327. Any Edition

F. Landis Markley, John L. Crassidis, *Fundamentals of Spacecraft Attitude Determination and Control*, ISBN: 9781493908028. Any Edition

Bong Wie, *Space Vehicle Dynamics and Control*. Any Edition

Course Outline

AE 434 Dynamics and Control (Lecture)

- Linear Control.
- Open loop and close loop system analysis.
- Modeling, linearization, parameter system identification and validation of dynamical systems.
- Transfer functions, State-space system representation and block diagrams.
- Steady-state error, PID control
- Concepts of stability and controllability. Stability criteria. Control design and analysis of dynamical systems in time and frequency domains.
- Control design via Root Locus
- Control design using Pole placement
- Introduction to LQR control

- Prerequisites: AE313 and AE 426 and MA 345/441

Questions?

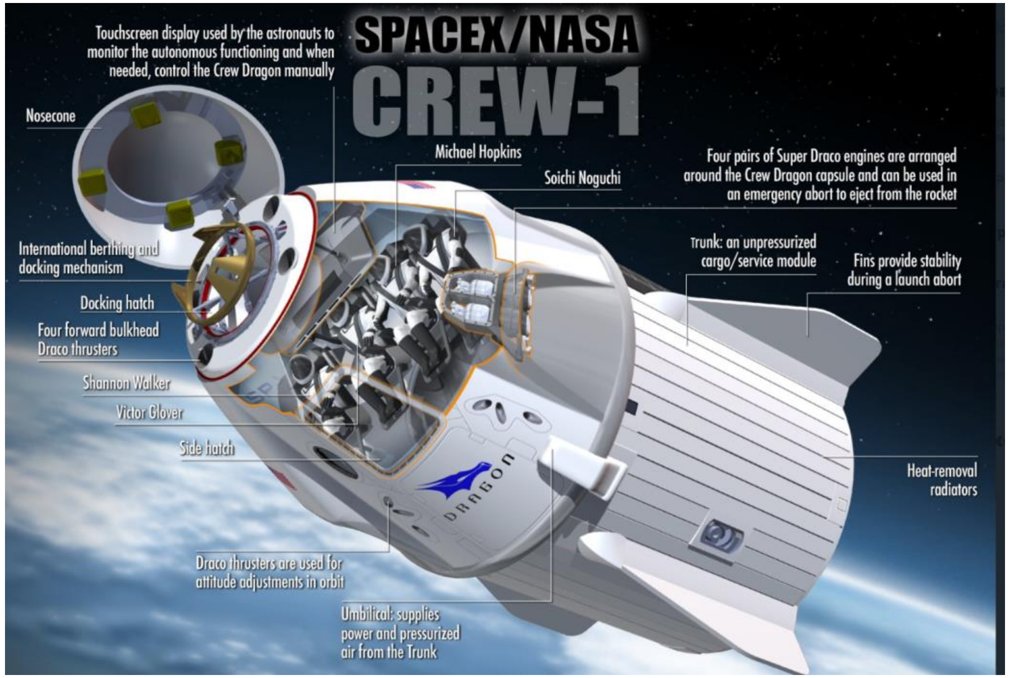
What is a Spacecraft?

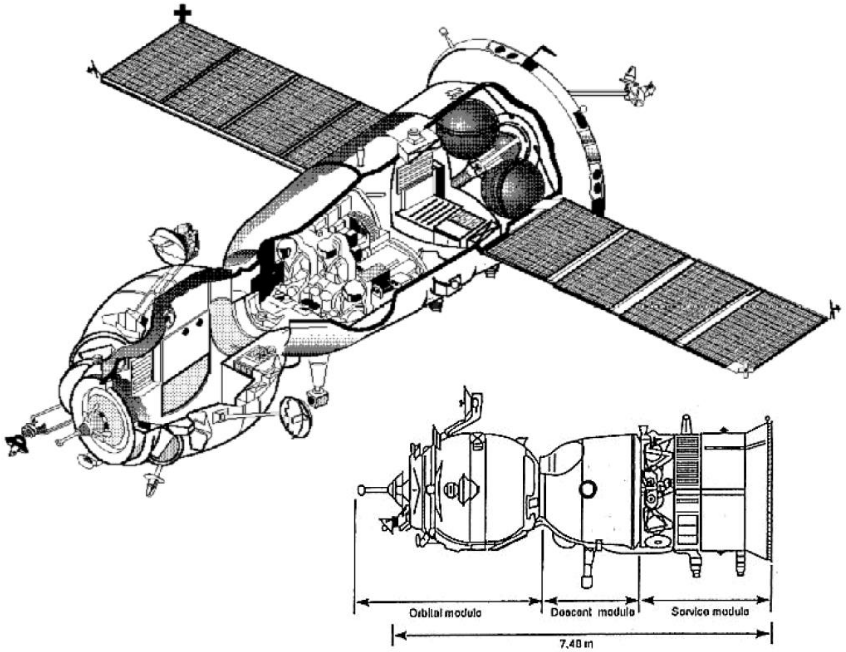
A vehicle or device designed for travel or operation outside the earth's atmosphere.

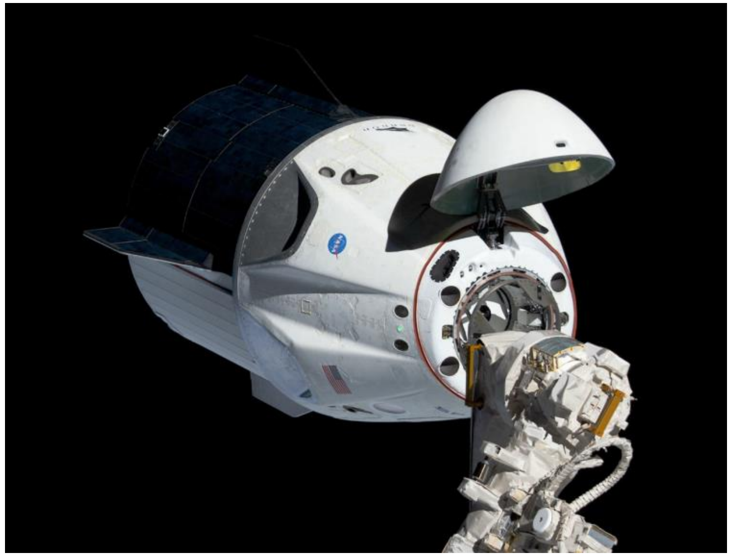
Types (non-exhaustive list)

- **Manned**
  - Space Shuttle, Soyuz, International Space Station, SpaceX Dragon, Orion
- **Unmanned**
  - *Remote observation*: Hubble, James Webb, Mars Reconnaissance Orbiter, Landsat, Venus Express, etc.
  - *Telecommunications*: Intelsat, XM and Sirius radio satellites, Starlink, etc.
  - *Navigation*: GPS, Glonass, Galileo, etc.
  - *Other*: Progress, ATV, Moon and Mars landers, defense, etc.

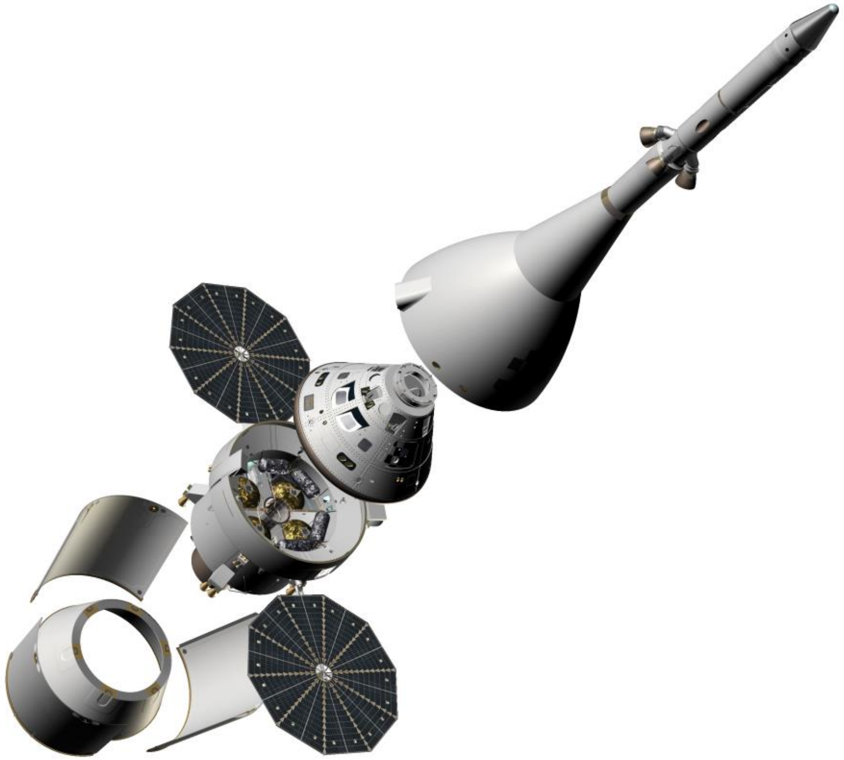
Soyuz Crew/Cargo Transport







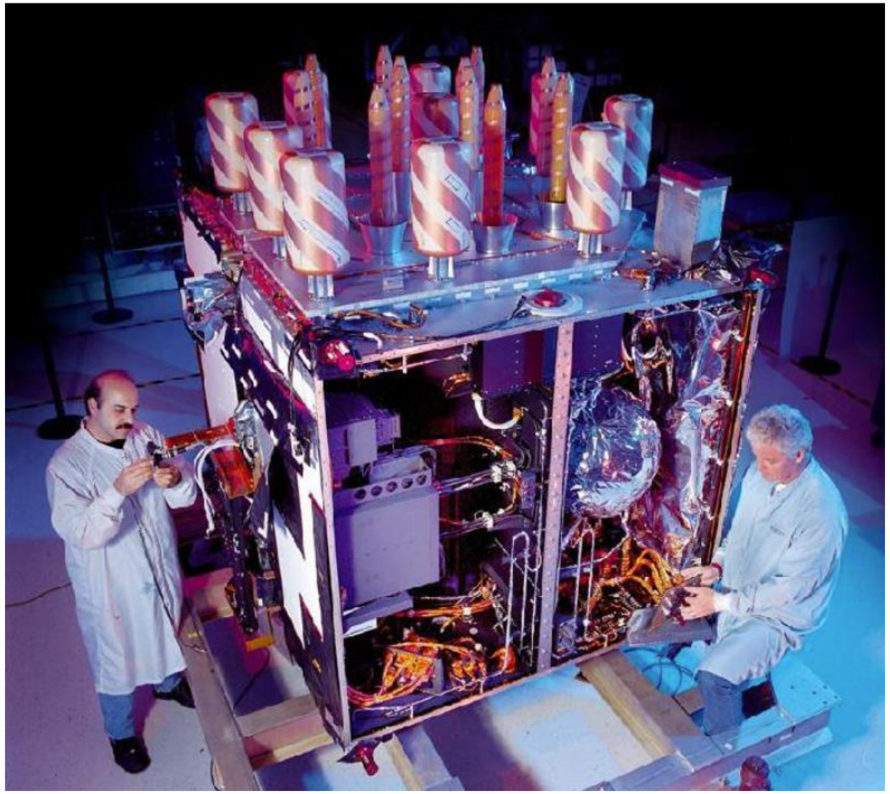
Orion Spacecraft



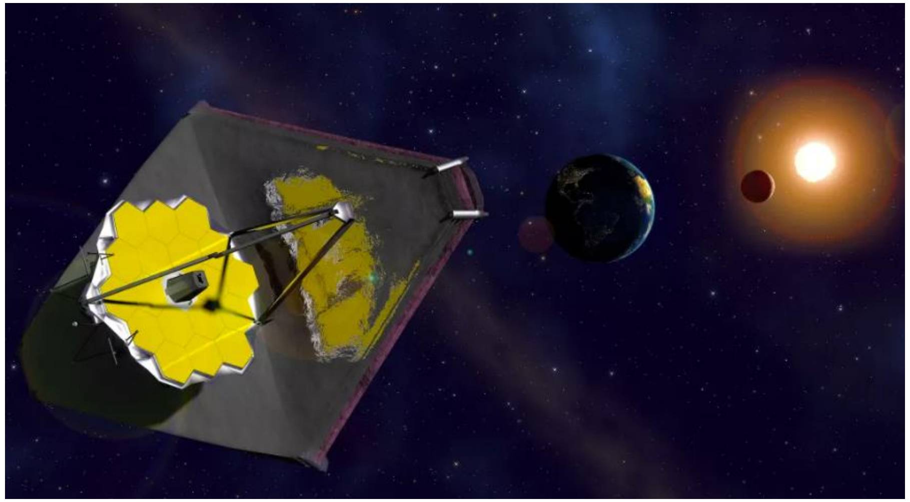
Cassini/Huygens – NASA/ESA/ASI

NAVSTAR - GPS

NAVSTAR = Navigation Satellite Timing and Ranging



Remote Observation



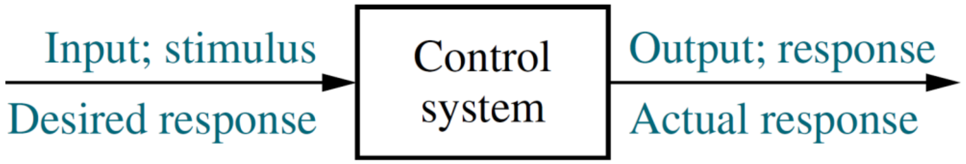
What is Control Engineering ?

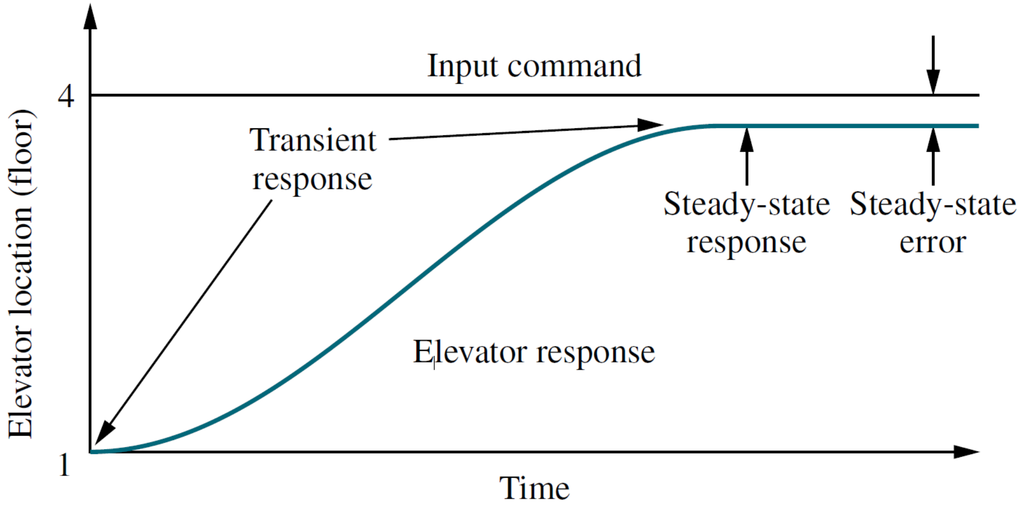
"to exercise restraining or directing influence over : regulate"

The aim is to make a system behave as we desire.

What is a control system?

A control system is an interconnection of components that will provide a system response.





What is Spacecraft Control?

We want to control:

1. Orbit (translational) control:
   - **Maintain** a certain orbit
   - **Transfer** from one orbit to another
   - **Rendezvous** and dock with another spacecraft

2. Attitude (rotational) control:
   - **Maintain** some subsystem **pointing** in a certain direction.
   - **Rotate** (**slew**) between an initial and a final pointing direction.

Obstacles to SC Control

- Why would an orbit change? (What perturbs the orbit?)
  1. Irregular gravity field
  2. Atmospheric drag (ISS orbit decays due to drag – propellant needed to raise)
  3. Solar radiation pressure
  4. Third body gravity

- Why would the attitude change? (What perturbs the attitude?)
  1. Magnetic field
  2. Solar radiation pressure
  3. Atmospheric drag
  4. Liquid fuel slosh

Spacecraft Control

To reduce complexity, we assume that the orbit and attitude control are decoupled:

1. Orbit control has a relatively low frequency (months to years –or never)

2. Attitude control has a relatively high frequency (seconds to tens of minutes)

Spacecraft Control Recap:

We need to control spacecraft (vehicles that work in space).

- Orbit (translational motion) and attitude (rotational or rigid body motion) are perturbed by:
  - External torques.
  - Internal torques.

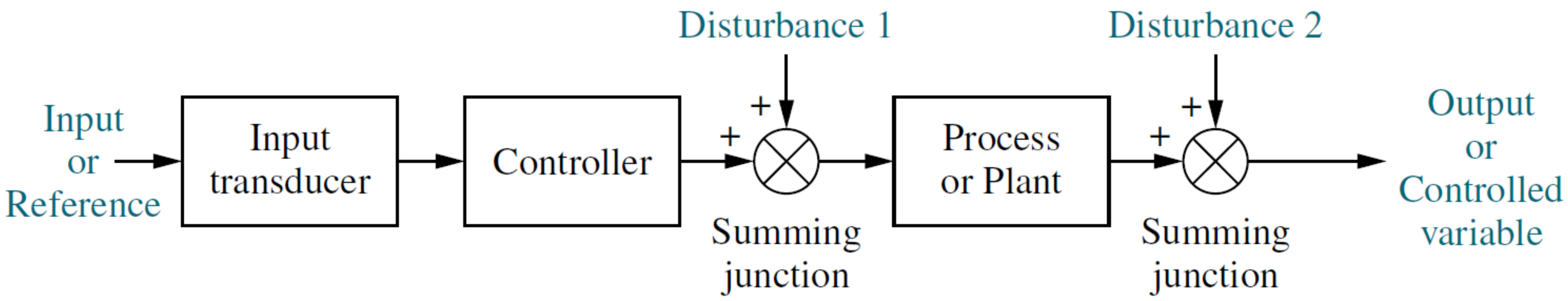
- Need to **compensate** for the perturbations **to maintain** the orbit and the attitude.
  - Perturbations can be secular or periodic or both.
  - Apply forces and torques (external or internal) to **reject** the perturbations.

- Need to **change** the orbit or the attitude according to mission requirements.
  - Apply forces or torques to **perform changes**.

Two major configurations for Control Systems:

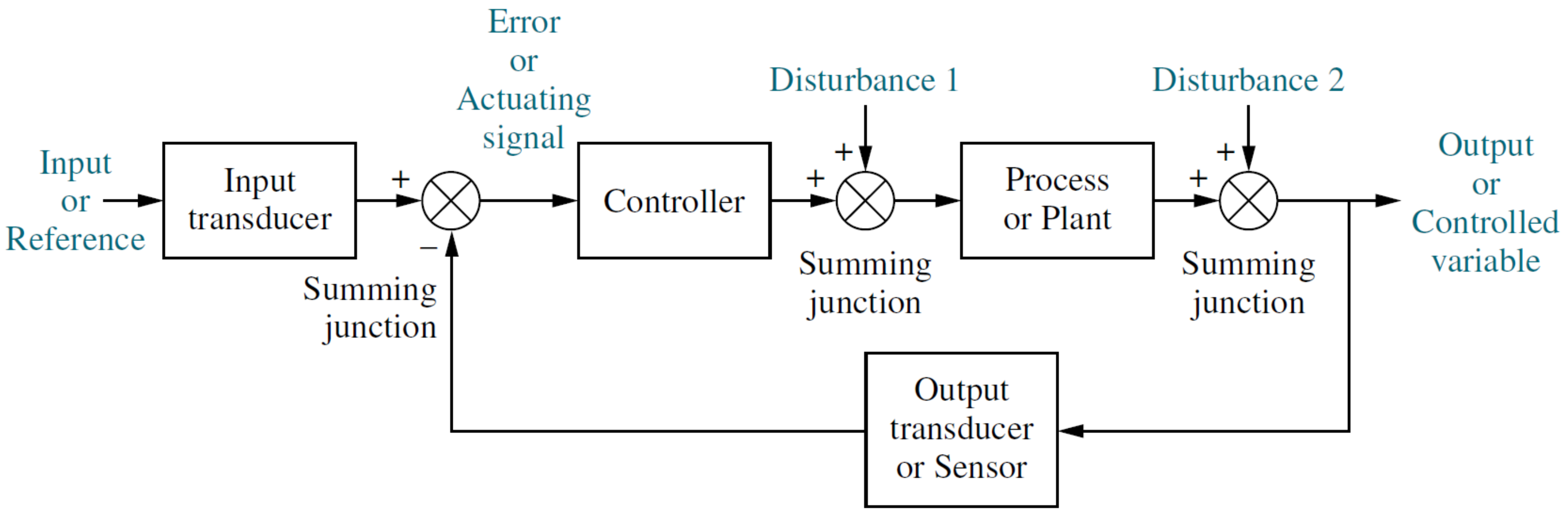
Open-loop Control

Control systems without sensors are called open-loop systems. The output has no influence on the control action of the input



Closed-loop/Feedback Control

- Compare actual behavior with desired behavior - make corrections based on the error
- Design control algorithm

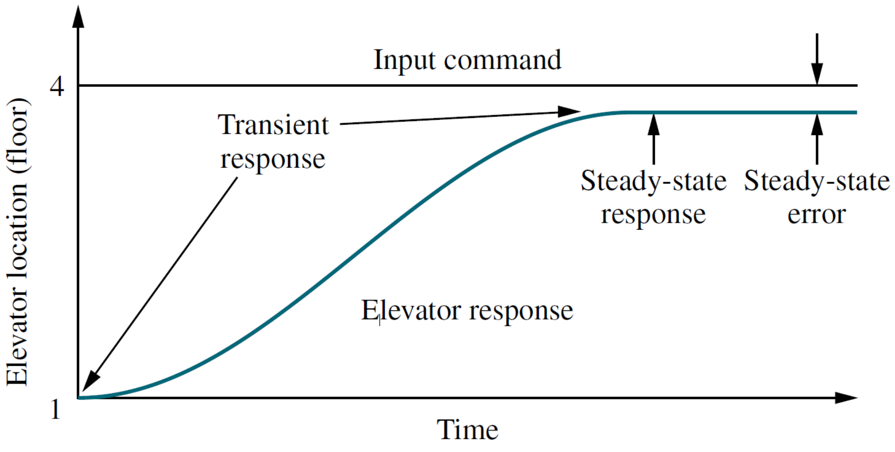


Control System Design Objective

Design a controller such that the output follows the reference in a satisfactory manner, even in the face of disturbances.

In other words, our goals are:

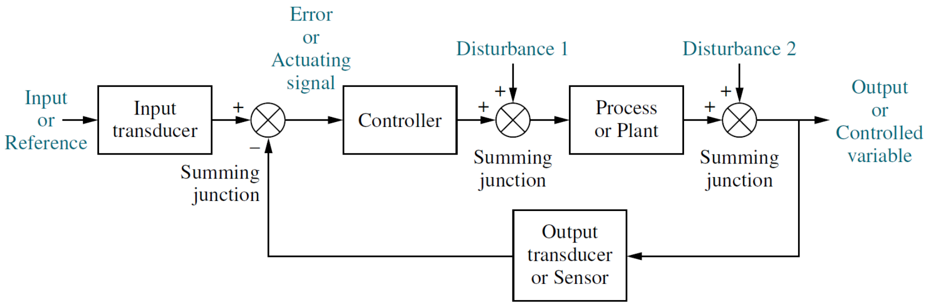
1. Producing the desired transient response
2. Reducing steady-state errors
3. Achieving stability



Goal for this course

Obtain a basic perspective on linear control theory and practice

- **Modeling a physical system**
  - Linearization of non-linear models
  - ODEs and their solutions – with Laplace transforms
  - Transfer functions
  - Block diagrams



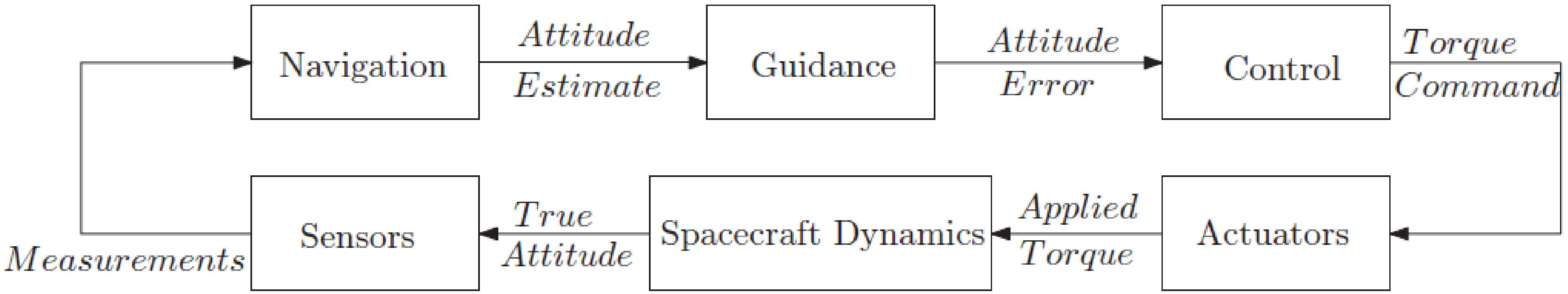
- **Analysis**
  - Time response
  - Steady-state error and PID control
  - Stability: Routh-Hurwitz criterion
  - Frequency response

- **Design control laws**
  - Root Locus
  - Frequency response
  - Pole placement
  - Introduction to Optimal control

Lead/Lag compensators

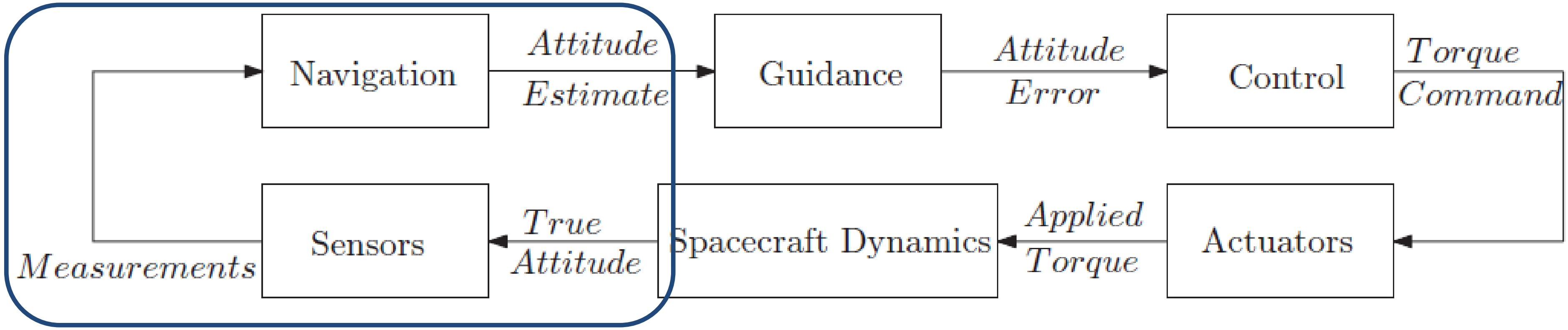
Spacecraft control system

- **GN&C is one of the spacecraft subsystems**
- **The control system typically consists of three parts**
  - Navigation – where am I?
  - Guidance – where do I want to be?
  - Control – how do I get there?
- **Interfaces with sensors and actuators** (**brain of the spacecraft**)



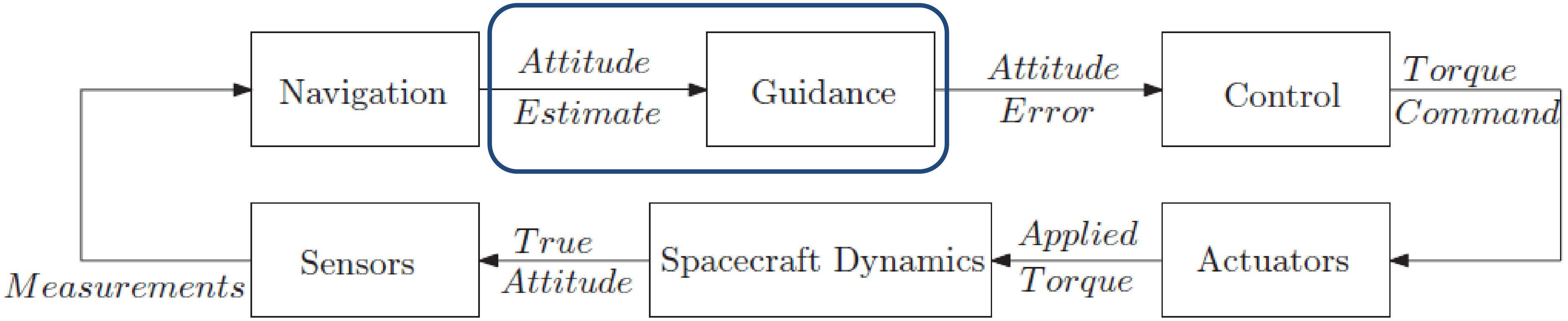
Spacecraft control system

- *Navigation Function (where am I?)*
  - **Based on sensor measurements, estimates the current dynamical states**
  - **Why not rely solely on sensor measurements?**
  - **Typical navigation techniques**
    - Sensor fusion
    - Stochastic filtering



Spacecraft control system

- *Guidance Function (where to go?)*
  - **Based on mission requirements, specifies desired dynamical states in the form of waypoints vs. time**
  - **May include a trajectory generator to smooth out the transition between waypoints**



Spacecraft control system

- *Control Function (how to get there?)*
  - **Based on desired and estimated states, calculates the required control actions such that the actuators force the current states to match the desired ones**